SOIL TEMPERATURES AS RELATED TO CORN YIELD IN CENTRAL IOWA

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ABSTRACT

Soil temperature data collected at the Iowa State College Agronomy Experimental Farm are analyzed in relation to corn yields. Some of the determining weather factors of soil temperature are evaluated. Monthly values of soil temperature at various levels are compared with corn yield in central Iowa and three physical relationships are discussed. In order to summarize the effect of these three relationships, a regression equation for the forecast of corn yield is proposed.

1. INTRODUCTION

Information on soil temperatures may well provide a key to increased corn yield and a program for lessening crop failure. These sub-surface temperatures are known to exert a controlling influence over plant growth from plowing and planting time to harvest. It is believed that the methods described in this report, concerned with the relationship of soil temperature to corn yield, could be adapted to the study of any type of plant growth.

Soil temperature measurements and analyses are not new. Over 100 years ago J. D. Forbes [4] measured soil temperatures at three locations near Edinburgh, Scotland, for varying depths down to 24 feet. The conclusions he drew then as to temperature waves and their propagation with increasing depth are still valid today. However, the use of this type of data has been largely neglected and only in the last few years is a systematic network of observations being attempted. The following report is preliminary and points to the vast potential usefulness of soil temperature data in modern agricultural research.

The purpose of this report is to examine the relation of soil temperature to corn yield in central Iowa. The regression equation for the forecast of corn yield is given to summarize the effects of soil temperature alone. The accuracy of the forecast could be improved by including other elements, such as soil moisture, but that is not the aim of this study.

Soil temperature data were obtained from the Agronomy Farm weather station, 4 miles southwest of Ames, operated cooperatively by Iowa State College, the Iowa Department of Agriculture, and the U. S. Weather Bureau. The Webster silty clay loam soil is fairly typical of Iowa's better farm land of recent glacial origin. Readings are taken from long mercury thermometers that extend into the ground but may be read without being extracted. The ground is kept bare of vegetation and is cultivated to a depth of 2 inches after each important rain.

The period of record for the various levels used in this report is given in table 1. Readings were made at 7 a. m., 12 noon, and 7 p. m. CST except during the period of February 1942 through August 1945, when they were taken one hour earlier.

The average soil temperature for the periods indicated will be referred to hereafter as the mean. In order to utilize the entire record of soil temperature data as listed in table 1 for analyses described in the last two sections, it has been necessary to adjust the temperature of the 1-inch level for the 4-year period when observations were taken 1 hour earlier, and of the 24-inch and 48-inch levels, since readings for the last 3 years were at 20 and 40 inches, respectively. In most cases the adjusted means were the same and in no case did the change amount to more than 1°. The final computations presented in sections 3 and 4 are based on the 7 a. m. readings and no adjustment was made to the original data.

2. SOIL TEMPERATURE AS A COMPONENT OF CORN DEVELOPMENT

Figure 1 gives a chronological comparison of soil temperatures and corn development and as such contains much of the data basic to this study.

TABLE 1.—*Period of record of soil temperature readings*

	Depth (inches)										
	1	2¼	4	6	8	12	20	24	40	48	72
Began	July 1937	April 1946	November 1949.	July 1937	November 1949.	July 1937	November 1949.	July 1937	November 1949.	July 1937	July 1937.
Ended	1953	1953	1953	October 1949.	1953	October 1949.	1953	October 1949.	1953	October 1949.	1953.

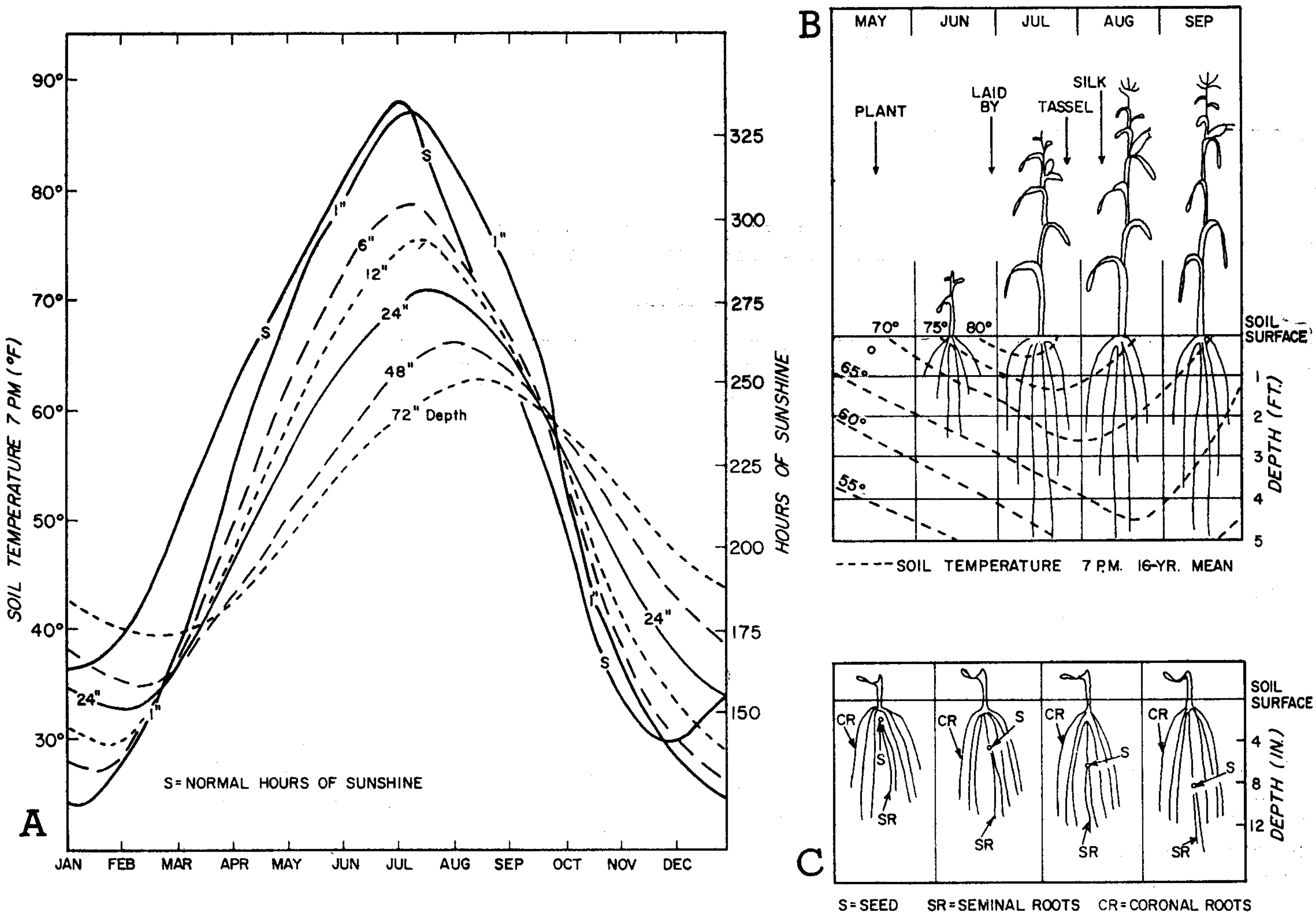

FIGURE 1.—Soil temperature as a component of corn development. (A) Mean annual soil temperature waves (1938–53) and normal annual hours of sunshine. (B) Schematic diagram of corn development compared with mean soil temperature of various depths and months. (C) Root development. The majority of roots (coronal roots) arise at the subcrown internode, about an inch below the soil surface, regardless of the depth the seed is planted.

The schematic drawing of corn growth in figure 1B emphasizes the most important phases of the plant's life cycle. The seed is planted 2 to 3 inches deep about May 15. The soil temperature in the seed bed should be in the upper 50's (°F.) or higher for proper germination [23], and as shown in the figure, usually it is in the upper 60's. The crop is normally laid by (receives its last cultivation) by the first of July. During the time of tasseling, July 20–25, and silking, August 5–10, the plant is particularly sensitive to the weather [16, 18].

Another important factor in this study is root development. Figure 1C illustrates the two types of roots produced by corn [11]. The seminal roots develop from the lower end of the embryo and though they often penetrate to depths of 5 to 6 feet and remain active until the plant matures, the coronal roots which arise at the subcrown internode become more important once they are established. Regardless of the planting depth, the main mass of roots joins the plant about 1 inch below the soil surface, making the temperature at that level of great importance throughout the entire growing season. During the first weeks of the plant's life, underground growth is faster than above ground. By the latter part of June the roots normally have penetrated to a depth of 2 feet, The roots usually grow 5 to 6 feet deep [5]; however there are exceptions due to extremes in soil moisture, soil density, and plant variety.

Figure 1A contains graphs of the normal hours of sunshine and the annual soil temperature waves. The soil temperature curve at 1 inch closely follows curve S, the normal hours of sunshine, and the main difference between the other temperature curves is a damping of the amplitude and a lag of the time of the maximum and minimum temperatures with increasing depth. The tracing of the mean 60° and 75° F. isotherms is of paramount importance. The temperature reaches 60° at the 2-inch level in April, at the 2-foot level in May, and at the 6-foot level in July. This sequence precedes seed and later root development by 3 to 6 weeks. The 75° isotherm appears near the surface in early June and disappears in late August. Normally its maximum penetration is a little over 12 inches in July. In section 4 it is shown that displacement of these two lines is associated with corn yield.

Figure 2 focuses attention on some of the problems

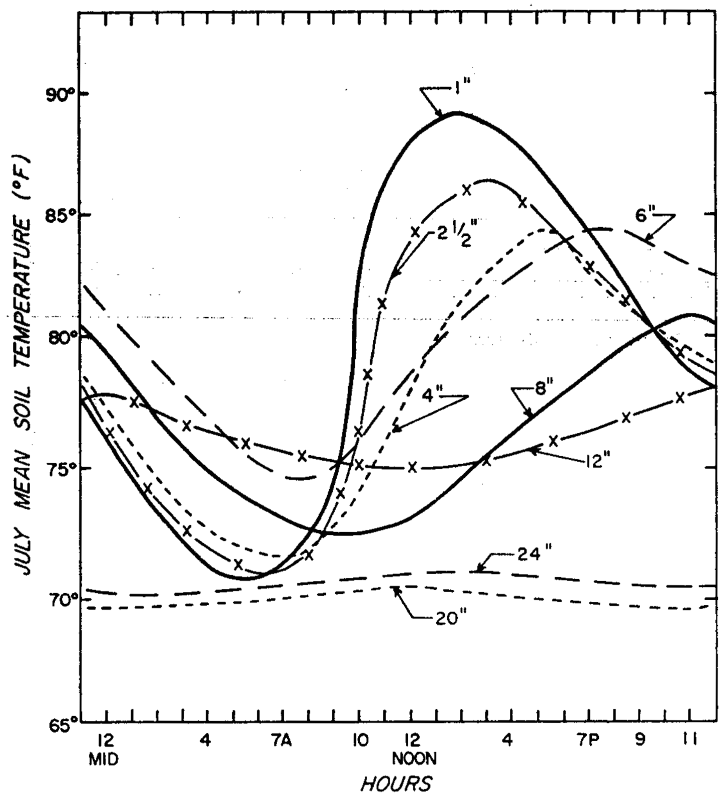

FIGURE 2.—Mean diurnal temperature waves for various depths for the month of July (1938–53 or less) showing time of maximum temperature.

encountered in summarizing and using soil temperatures. Maximum and minimum readings are usually lacking and if available would occur at different times for different depths. In the first 12 inches, the noon reading is closest to the mean temperature [19], but the sharpness of the temperature rise at that time, as compared with either 7 a. m. or 7 p. m., subjects the noon observation to more fluctuation. As indicated earlier, the different times of readings used in this report would require a correction factor for the evening data which may be ignored with the morning temperatures; the 7 a. m. data are used in sections 3 and 4. The lower temperature at 20 inches than at 24 inches may be accidental because data for different periods of record were used for the two levels.

In comparing figures 1 and 2, it will be noted that the mean temperature at the 1-foot level rises about 7° from June to July; while the diurnal change during the month of July is only about 3°. For levels near the surface this is reversed. At 6 inches, the monthly change from June to July is also 7°, but the diurnal change during July is 10°. For readings below 6 inches, diurnal changes can be assumed minor as compared with monthly changes.

3. FACTORS DETERMINING SOIL TEMPERATURE

To interpret properly relations of soil temperature to corn yield it is desirable to have a practical understanding of the relation of some easily measured weather elements with soil temperature. The elements considered in this report are air temperature, percent of sunshine, rainfall, and persistence.

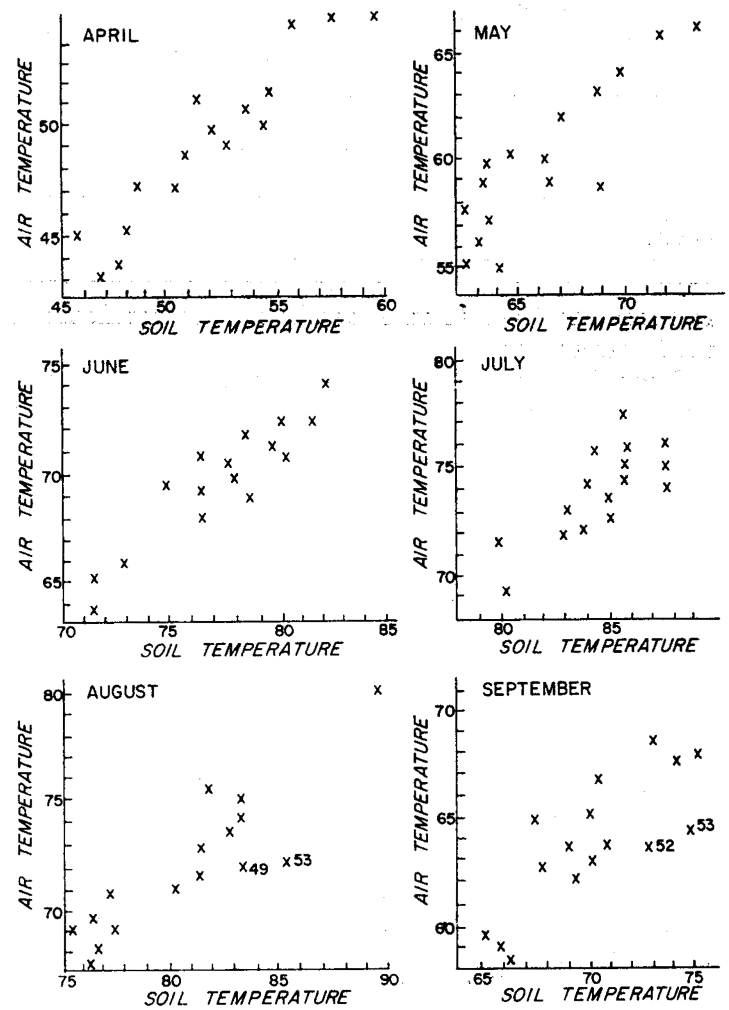

FIGURE 3.—Mean monthly air temperature compared with 7 p. m. 1-inch soil temperature, April through September (1938–53).

The relation of soil temperature (surface) to air temperature is shown in figure 3. Neither is the sole cause or result of the other, but both result from the same environment. Much of the variation is caused by soil moisture, which affects the thermal properties of the ground. For example, Iowa had very dry weather during August 1949, September 1952, and August and September 1953. As shown in figure 3, the soil temperature for those months was much higher than the air temperature when compared with the same months in other years. For this reason, and by correlations presented later, soil temperature may be considered as a better measure of drought than air temperature.

Table 2 shows the correlation of the mean 1-inch 7 a. m. soil temperature for May through August at Ames with (1) percentage of sunshine at Des Moines; (2) rainfall at Ames (to give further weight to very dry weather, rainfall was arbitrarily classified: 1 unit for each ½ inch up to 2½ inches, 1 unit for each inch from 2½ to 7½, and 1 unit for each 2 inches above 7½ inches); (3) lag in soil temperature, which is the persistence from one month to the next. Table 3 contains the same weather elements and their relation to depth for the month of June. For the number of observations available, correlation values less than 0.426

TABLE 2.—*Correlation of 7 a. m. mean monthly soil temperature at the 1-inch level for May through August with percentage of sunshine, rainfall, and lag from preceding month. Values above 0.426 are significant at the 10 percent level.*

	Month			
	May	June	July	August
Sunshine	0.677	0.556	0.310	0.547
Rainfall	−.314	−.185	−.207	−.344
Lag	.143	.417	.669	.352

at 1 inch and 0.497 at other depths are not significant at the 10 percent level.

Curve S in figure 1A shows that the normal hours of sunshine received in Iowa during the year closely parallels the lines of soil temperature. In table 2, correlations of soil temperature to percentage of sunshine are significant in May, June, and August; while in table 3 they are significant through the 6-inch depth. Table 3 also shows that June soil temperature at 48 inches and 72 inches is somewhat related to the percentage of sunshine of the preceding month.

Rainfall, as soil moisture, plays the most complex and often contradictory role in soil temperatures. Crawford [2] lists the thermal properties of the soil that are influenced by soil moisture, and points out that some of these properties may exert opposing effects. Brooks and Fitton [3] give definite values of soil temperature in dry ground compared with wet ground: "The presence of moisture in soil tends to give a low uniform temperature; . . . At Columbia, Mo., wet ground averages one degree less than dry ground at 12 and 36 inches . . ." Lawrence [10] referring to the spring "dryout" at Rothamsted states that frost frequency increases or decreases less rapidly as the soil dries out, in spite of steadily increasing soil temperatures. In general agreement with most investigations it may be stated, assuming many simplifications, that the effect of soil moisture is to stabilize temperatures, offering resistance to change.

Coupled with the varying effects of soil moisture, rainfall has a unique effect on soil temperatures. It is the only cause of large nearly simultaneous temperature change at all depths down to the 2-foot level. Soil temperature changes resulting from the percolation of rain differ entirely from normal thermal diffusion. Rainfall has no significant correlation with soil temperature, but its relation is negative in all months. The low correlations of rainfall with soil temperature are considered to be more a result of the opposing effects mentioned above than of any lack of relation.

The persistence in anomalies of all weather elements is well known. The lag correlation in table 2 is a sum of persistence in causative weather variables and heat storage of the soil. The lag correlation in table 3 steadily increases with depth, until at the 6-foot depth it is significant at the 1 percent level.

The correlations discussed hold little promise for predicting soil temperatures but are summarized here for such value, positive or negative, as they may hold for other attempts of this nature.

TABLE 3.—*Correlation of 7 a. m. mean soil temperature for the month of June by depths with percentage of sunshine, rainfall, and lag from the preceding month. Values above 0.426 are significant at 1-inch and 72-inch depths and above 0.497 at 6-, 12-, 24-, and 48-inch depths at the 10 percent level.*

	Depth					
	1 in.	6 in.	12 in.	24 in.	48 in.	72 in.
Sunshine	0.556	0.587	0.467	0.465	0.420 *.161	0.221 *.336
Rainfall	−.185	−.195	−.330	−.272	−.272	−.190
Lag	.417	.254	.487	.523	.544	.738

*Correlation with May sunshine.

4. SOIL TEMPERATURES AND CORN YIELD

Corn is Iowa's most important field crop and there is an ever-increasing demand for estimates of yield. A formula for the forecast of yield is presented herewith, but the main objective of this report is to evaluate in as precise statistical terms as possible the relation of certain soil temperature readings to corn yield.

Corn yield has increased in central Iowa during the last 70 years. Barger and Thom [1] report an increase of about 8 bushels per acre from 1891 to the mid-1930's, with an increase of another 10 bushels per acre from the mid-1930's to the early 1940's. The first increase was produced by generally improved cultural practices. The great jump that came in the late 1930's was caused in large part by widespread acceptance and use of hybridization. The data considered here were all obtained during the period of hybridization except for 1938 and 1939. The 1938 and 1939 yields were adjusted upward from 59.3 to 64.0 bushels per acre and from 59.3 to 60.0 bushels per acre as described by Barger and Thom. A linear regression line fitted to yields from 1940 through 1953 indicates a slight decline of about 1½ bushels per acre during this period. The period is too short to indicate a trend, but it has eliminated the need to adjust upward the early yields (with the exceptions of 1938–39). On a national scale, where general acceptance of hybrid varieties came more slowly in the years after 1937, a significant trend in yields might exist.

Table 4 contains the corn yield for the central district of Iowa (Agriculture Marketing Service Crop Reporting District), along with a very simplified list of the major detriments. This district is composed of 12 central counties of Iowa and comprises an area of slightly more than 6,000 square miles. Yields quoted are from the Iowa Agricultural Year Books, except 1938–39 as indicated above.

The first 2 years listed in table 4 deserve special attention. The year 1947 had the most disastrous corn weather in recent years, and the only really poor crop of the period considered. As reported in the Annual Iowa Climatological Summary under direction of Thom [22], "The dependence of Iowa agriculture upon the vagaries of the weather was closely demonstrated during the 1947 season. A cool wet spring delayed crop planting activity and plant growth; then, in addition, a hard freeze on May 29th . . . further set back the corn. The heavy

TABLE 4.—*Corn yield (bushels per acre) and major detriments in central Iowa, 1938–53.*

Year	Yield	Detriment
1947	28.8	Cold and wet early in the season, hot and dry late in the season.
1949	46.0	Dry, and corn borer.
1951	48.9	Cold and wet.
1945	49.1	Cold and wet.
1950	50.2	Cold and wet.
1944	52.4	Hot and dry.
1953	56.0	Partial drought.
1941	57.3	Short drought.
1940	57.7	Short drought.
1939	60.0	
1943	61.2	
1946	63.0	
1938	64.0	
1948	65.0	
1942	66.5	
1952	67.0	

rains and subsequent floods during June caused appreciable crop acreage to be abandoned . . . followed by a hot dry weather regime that persisted from mid-July through the first decade of September."

The year 1949 had the second smallest corn yield in recent years. As described by Lamoureux [9] in the Annual Iowa Climatological Summary, "The year 1949 saw the greatest infestation of corn borer in the history of corn in Iowa. Early prospects for another bumper crop [the yield of the previous year 1948 had been exceeded only once at that time] were canceled by the persistence of dry weather in some sections and by the corn borer pest in all sections."

As far as has been determined, the only other work done relating corn production with soil temperatures was published in 1910 by Hunt [8]. In that report, 4 years of soil temperatures at unspecified levels during 1882–85 were compared with the moisture content of the corn. Low soil temperatures (presumably means for the growing season) were related to high moisture content at harvest time and, while moist corn does not necessarily mean low yield, it may mean a low quality of corn. As shown in section 3 soil and air temperatures differ. Soil temperature can change rapidly under strong solar radiation and air temperature can be modified quickly by advection. Of these the solar heating of soil (and plants) is considered to be the primary influence on crop development. Since soil temperature is a function of many factors it is used as the independent variable in this study without the loss in degrees of freedom which years ago plagued Mattice [12] and others using multiple correlation methods.

While soil temperatures are investigated here, earlier studies of air temperature indicate that plants respond differentially to heat energy available during progressive stages of the growing season. Various investigators have found the following three basic types of relation between air temperature and corn yield:

1. Smith [21] by simple correlation found a high positive relation between corn yield and June temperature in Ohio. Rose [17] obtained the same results later; he also found that within the same State some weather elements correlated positively in some areas and negatively in others. Wallace [23] stated that high correlations were notably lacking in the central corn belt, including Iowa. Later Wallace and Bressman [24] concluded that for most of Iowa the worst corn weather was cool wet weather in May, June, and August, which results in a slight positive correlation.

2. Smith [20] speaks of optimum conditions for a crop, so that any departure, either positive or negative, lowers the yield. Houseman and Davis [7] attacked this problem in western Iowa by means of regression statistics. The general principle was set out by Reed [14]: "Crops in Iowa, under exceptionally intelligent husbandry have become adapted to the prevailing weather. Any important departure above or below normal weather is deleterious . . ."

3. Mills [13] by simple correlation found a large negative correlation between July temperature and corn yield in Kansas. An even larger negative value was found by Hodges [6] using methods of curvilinear regression.

In this study, correlating soil temperature with crop yield, the same three basic types of correlation were found for three periods during the crop season. Figure 4 is composed of scatter diagrams of corn yield versus the departure from the mean of the 7 a. m monthly soil temperature at various levels, May through August. The three types of relationship may be observed:

1. Positive correlation early in the season. All levels in May and the 48-inch and 72-inch levels in June and July show some positive relation; the maximum correlation at 48 inches occurs in June. This is a reflection of the earliness of the season. High soil temperatures early in the season reflect mildly dry weather. One of the worst effects of a wet spring and early summer is that it limits plowing and cultivation. It also retards plant growth. Reed [15] says that most Iowa corn crop losses are caused not by early fall frosts but by the sequence of cold spring weather, late planting, and early frost. On the other hand he points out that a June air temperature 2° or more above normal virtually assures crop maturity ahead of fall frost.

2. Negative correlation with any departure from the mean in the middle of the season. As early as May at 6 inches (fig. 4) maximum yields are associated with temperatures near the mean. Large positive or negative departures are detrimental. Optimum conditions for the crop in the upper 2 feet during June are shown by the negative correlation with departures from the mean and are centered at 12 inches. During June the corn plant grows rapidly and is very sensitive to any extreme conditions. This is the strongest of all correlations; it has not appeared as such in previous investigations. The reason for the high correlation found in this study may be (1) use of soil temperatures instead of air temperatures, or (2) use of hybrid corn which is especially designed for average local conditions. As described in section 2, root development passes through the 1- to 2-foot level in June and is probably the reason that the core of high correlation is near that level. In July and August this negative correlation tendency is not so noticeable.

3. Negative correlation late in the season. In August

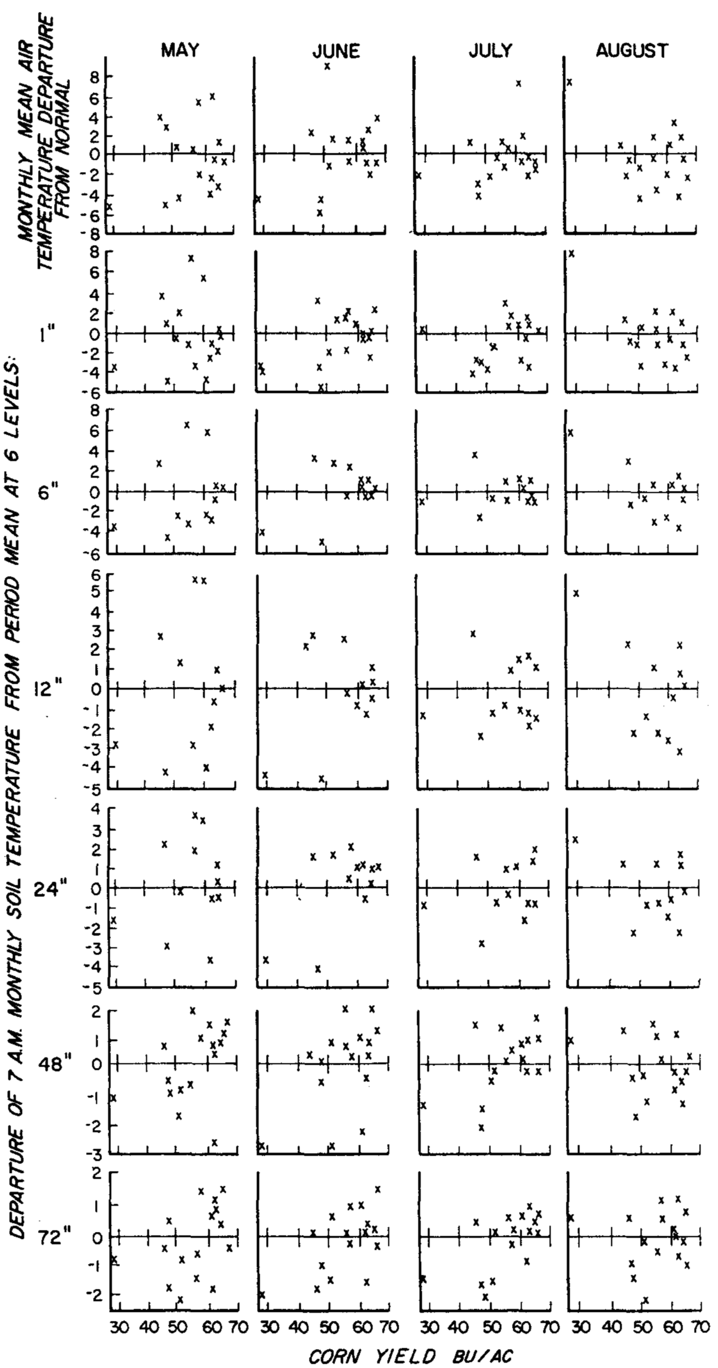

FIGURE 4.—Scatter diagrams of corn yield plotted versus the departure from the mean of the 7 a. m. 1-, 6-, 12-, 24-, 48- and 72-inch soil temperature and the mean air temperature, May through August.

the slope is negative in the upper 24 inches but returns to positive at the 72-inch level, characteristic of the earlier months. This August negative correlation has a peak at the 1-inch level. This may be termed the drought factor. Hot dry weather in August reduces the corn crop considerably, but seldom if ever does soil temperature get low enough in August to be detrimental in central Iowa. This causes the single hot dry August in 1947 to bear much of the weight of the correlation. A somewhat similar case occurred after the period of this study, when lack of rain during July and all of August (the 7 a. m. 1-inch soil temperature was 3° above normal) reduced a very promising crop in 1955. Two reasons are given for the core of negative correlation at 1 inch: (1) the upper stratum of the ground receives the full heat of sunshine so that during periods of dry weather excessive heating tends to magnify the drought conditions, sometimes resulting in severe damage to the crop; (2) as earlier shown, most of the roots branch off the stalk about an inch below the surface of the soil and are sensitive to the temperature at that level.

TABLE 5.—*Absolute values of simple correlations of corn yield with the 7 a. m. 1-inch through 72-inch soil temperature and the mean air temperature, May through August, showing the centers of the three types of correlation. Unboxed area=positive correlation; Single boxed area=negative correlation with departure from mean of period; Double boxed area=negative correlation. Correlations are significant at the 10 percent level when over 0.425 at the 1- and 72-inch levels and with air temperature, and when over .496 at 6, 12, 24, and 48 inches (data 1938–53, or less).*

	May	June	July	August
Air	0.129	0.511	0.248	0.448
1″	.166	.628	.039	.613
6″	.271	.769	.045	.581
12″	.160	.777	.146	.507
24″	.159	.720	.275	.315
48″	.341	.567	.447	.082
72″	.415	.555	.561	.479

Table 5 contains the absolute values of each type of simple correlation with corn yield.

Three groups of data were chosen to represent each type of relationship in order to formulate a basic regression equation: the 72-inch June temperature, the 1-inch 7 a. m. June temperature, and the 1-inch 7 a. m. August temperature. As indicated earlier, readings since 1949 have been taken at the 2¼-, 4-, 8-, 20-, and 40-inch levels instead of the 6-, 12-, 24-, and 48-inch levels computed in this report. That is the reason the 1-inch June reading is used in the regression equation, even though the 12-inch correlation is higher, and similarly, the 72-inch June reading instead of the 48-inch value. When more of the new readings are available, intermediate levels, nearer the cores of the correlations should be used. The following regression equation is the result of the multiple correlation of the three groups of data:

$$X_1=28.0756+3.0272X_2-2.1556X_3-1.9487X_4$$

$s_{1.234}=5.68$ $\quad r_{12}=0.555$ $\quad r_{12.34}=0.323$ $\quad \beta_{12.34}=0.327$

$R_{1.234}=0.811$ $\quad r_{13}=-0.628$ $\quad r_{13.24}=-0.509$ $\quad \beta_{13.24}=-0.356$

$r_{14}=-0.613$ $\quad r_{14.23}=-0.564$ $\quad \beta_{14.23}=-0.538$

where:

X_1 =Corn yield
X_2 =June 72-inch soil temperature
X_3 =Departure from the mean of the June 1-inch 7 a. m. soil temperature
X_4 =August 1-inch 7 a. m. soil temperature
$s_{1.234}$ =Standard error of estimate of regression formula

$R_{1.234}$ = Multiple correlation coefficient of regression formula

r_{12} = Simple correlation of 72-inch June soil temperature with yield

$r_{12.34}$ = Coefficient of partial correlation of 72-inch June soil temperature

$\beta_{12.34}$ = Beta coefficient of 72-inch June soil temperature

The coefficient of multiple correlation $R_{1.234}$ is a measure of the combined relation of the three parameters to corn yield. For the 16 years 1938–53, F-tests show it to be significant at the 1 percent level. The statistic r_{12} is the coefficient of correlation of the 72-inch June soil temperature to corn yield, while $r_{12.34}$ is the coefficient of partial or (net) correlation of the same parameter. The latter is the relationship between corn yield and the single independent variable (72-inch soil temperature) when the other two factors included in the study are held constant.

There is a relationship, mainly persistence, between weather phenomena of adjacent months and it is not surprising that there is a considerable interrelation between the three parameters used in the above equation. All the partial correlations show smaller values than the simple correlations for the same variables. It is shown that the net effect of 72-inch June soil temperature upon corn yield is distinctly less than was indicated by the simple correlation.

The 1-inch June soil temperature shows the highest correlation when considered alone, but after the effect of the other two variables has been minimized, the partial correlation ranks second to the 1-inch August soil temperature. The June 1-inch variable has been measured as a departure from the mean; and the partial correlation of this variable has a relation to below normal temperatures of the 72-inch June variable and a relation to above normal temperature of the August 1-inch variable; thus generally speaking, the middle variable was reduced more than the other two variables, and may rank somewhat higher than the partial correlation indicates.

Beta coefficients are another expression of the relationship between the variables. $\beta_{12.34}=.327$ may be taken to mean that with a decrease of one standard deviation in June 72-inch soil temperature, when the other two factors are held constant, the corn yield decreases .327 of one standard deviation. Putting this in the original dimension and holding the other variables constant: a decrease of 1° at 72 inches in June will decrease the yield by 3.13 bushels per acre; a displacement of 1° away from the mean of the June 1-inch soil temperature, either above or below, will decrease the yield by 2.16 bushels per acre, and an increase of 1° of the August 1-inch soil temperature will decrease the yield by 1.95 bushels per acre.

The following is an example of the proposed formula applied to independent data, 1954. Yield that year was 56.2 bushels per acre or just slightly above the normal which is 55.8 bushels per acre.

$$X_2=54.8, \quad X_3=1.7, \quad X_4=66.7$$

$$X_1=28.0756+3.0272(54.8)-$$
$$2.1556(1.7)-1.9487(66.7)=60.4$$

The proposed formula forecasts a yield of 4.2 bushels per acre above the actual 56.2 bushels per acre. The basic value of this corn yield versus soil temperature experiment is the establishment of quantitative relationships. One use of these relationships is in the early estimation of corn yield, but the size of the standard error of estimate ($s_{1.234}=5.68$ bushels per acre) should be kept in mind.

The 72-inch June 1954 soil temperature forecasts a 1954 yield of 58.9 bushels per acre. The 1-inch June 7 a. m. soil temperature forecasts about the same, 60.1 bushels per acre. A combination of both June parameters, which are available on the first of July indicates 59.5 bushels per acre. As this forecast is from June data and encompasses only normal change through the rest of the season, as based on the data of the preceding 16 years, some refinement may be achieved by using the Weather Bureau's 30-day outlook. For July 1954 central Iowa was placed in the transition zone from above to much above normal temperatures with subnormal rainfall. On this basis the forecast available July 1 of 59.5 bushels per acre would appear too high, and judgment reduction would be in order. On August 1, the 30-day outlook called for a change to above normal rainfall and subnormal temperature. On this basis and including the storage of excess heat from July, an August soil temperature of only slightly above normal could be assumed (about the same as the observed value) and the last "early" forecast issued using this information. The exceptionally accurate 30-day outlooks in 1954 made this corn yield forecast fairly accurate.

Let us now apply the formula to data for 1955. As mentioned earlier, prospects for a bumper crop early in July 1955 were considerably reduced by dry weather in late July and August. The actual yield was 54.3 bushels per acre.

$$X_2=55.4, \; X_3=2.6, \; X_4=70.0$$

$$X_1=28.0756+3.0272(55.4)-$$

$$2.1556(2.6)-1.9847(70.0)=53.7$$

The difference between the forecast and the actual yield for 1955 is very small, only 0.6 bushel per acre.

In 1956, a year that was dry throughout most of the growing season, the actual yield was only 51.6 bushels per acre. The formula forecast a yield of 58.4 bushels per acre, an overestimate of 6.8 bushels per acre.

$$X_2=55.1, \; X_3=3.2, \; X_4=66.5$$

$$X_1=28.0756+3.0272(55.1)-$$

$$2.1556(3.2)-1.9847(66.5)=58.4$$

5. CONCLUSIONS

Corn yield is related to the temperature of the soil and in Iowa reduced yields are associated with: (1) negative departures from the mean in May, with the relation strongest at 6 feet; (2) either negative or positive departures in June, with the relation strongest in the first 2 feet; (3) positive departures in August, with the relation strongest at 1 inch. The relation of soil temperature to corn yield is twofold: first, a direct influence on the development of the corn plant, and second, a measure of the effect of air temperature and moisture on the plant. During May, the relation of warm temperatures at 6 feet to high yield is indirect and is considered to be an indication of the earliness of the season. During June, the plant is small and the old Iowa adage, "knee high by the 4th of July," indicates a well-advanced stand; thus the relation of the 1-inch soil temperature in June is assumed to be direct. During August, the corn is 3 to 7 feet high, tall enough to shade the ground, and the relation is assumed to be more indirect than in June.

As described in section 3 soil temperature varies with different types of soil; therefore the mean temperatures, and their deviations from year to year as discussed in this paper, may not be applied to other soil temperature readings, even in the central division; also it should be borne in mind that these soil temperatures were obtained in fallow plots rather than in the field of corn. The Ames temperatures must be used as the standard for the central division and only after extended comparison with other readings could local refinement be achieved by using more local data.

The simplest case where a knowledge of soil temperatures may be put to use to increase corn yield is at planting time. If at that time, the 6-foot soil temperature is below normal and the outlook is for continued moist, cool weather, the corn yield prospect should be low. The temperature of the first few inches could be raised by ridge planting followed by shallow cultivation to aerate the ground, thus minimizing one of the worst threats to corn, a cold late spring.

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